RECONNAISSANCE PALEONTOLOGIC STUDY OF THE KISHENEHN FORMATION, NORTHWESTERN MONTANA AND SOUTHEASTERN BRITISH COLUMBIA

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mollusks

ABSTRACT

The Kishenehn Formation, a sequence of over 11,000 ft (3,350 m) of synorogenic deposits, has yielded fossils that include microfloral and megafloral remains, mollusks, insects, fishes, and mammals that suggest an age range between late Eocene and early Miocene. Radiometric dates from the deposits in the Kishenehn and South Fork basins are within the Oligocene. The fossils provide evidence for a climatic transition from sub-tropical to warm temperate conditions and development of several new taxa.

INTRODUCTION

The Kishenehn Basin of northwestern Montana and southeastern British Columbia is a narrow half-graben 95 miles (150 km) in length and ranges from about one to eight miles (1.6 to 13 km) in width (Fig. 1). Geographically, the basin has been divided into two regions, the North Fork and Middle Fork, each named after the branch of the Flathead River which cuts through that part of the basin. The smaller South Fork Basin, located to the southwest of the Kishenehn Basin, is a narrow graben about 45 miles (70 km) in length and commonly less than two miles (3 km) wide. Preserved in both basins are synorogenic, basin-fill sediments that attain a thickness exceeding 11,000 ft (3,350 m) in the Kishenehn Basin and possibly 5,000 ft (1,500 m) in the South Fork Basin. These grabens systematically subsided and accumulated nonmarine sediments of the Kishenehn Formation during the Eocene(?), Oligocene, and Miocene(?); hence, a complete and uninterrupted stratigraphic record for that interval is preserved. The Kishenehn strata exposed along cut banks of the Flathead River system typically consist of interbedded conglomerates, sandstones, siltstones, mudstones, marlstones, coals, and oil shales.

The first report of fossils in these rocks was in 1912, when Daly found mollusks along the North Fork in British Columbia. Later paleöntologic examination has produced additional mollusks as well as mammals, palynomorphs, and megafloral remains (MacKenzie, 1916; Russell, 1952, 1954; Ross, 1959; Hopkins and Sweet, 1976; McMechan, 1981). The paleontologic work discussed here began in 1967 along the North Fork, and was extended to the Middle Fork region after geologic study by Constenius (1981) revealed the extent and fossiliferous nature of Kishenehn deposits there. These investigations have produced extensive collections of fossil mammals, fishes, insects, gastropods, ostracodes, bivalves, palynomorphs, macroflora, and such rare fossils as bird feathers (Figs. 1 and 2).

The South Fork Basin has been less completely studied. A radiometric date of about 29.9 ± 5.3 Ma from a tephra indicates an age comparable at least in part to that of strata in the Kishenehn Basin. So far, significant fossil localities have not been found in the South Fork Basin, but our work there is continuing.

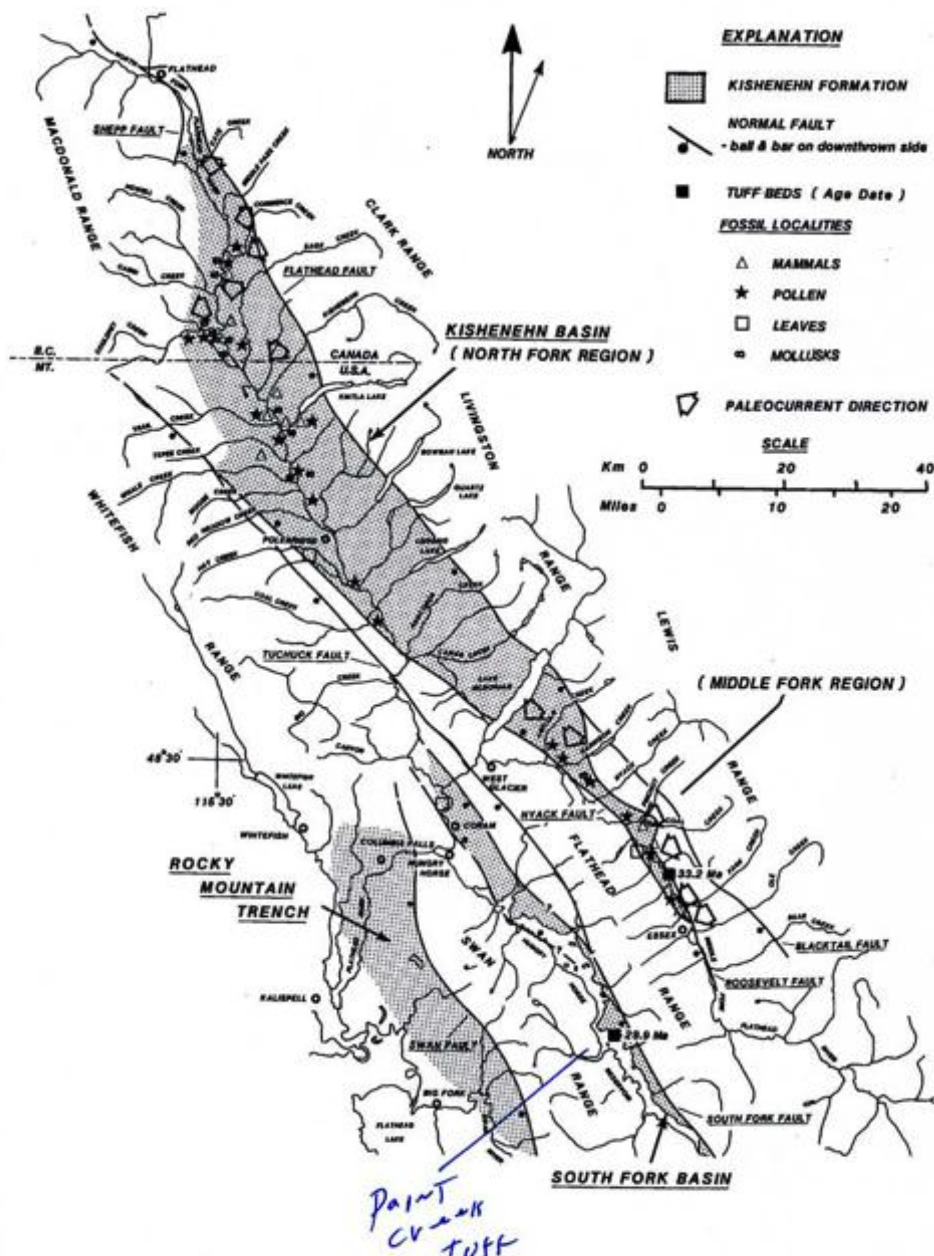


Figure 1. Generalized geology of the Kishenehn and South Fork basins with localities of fossils and age dates indicated.

GEOLOGIC SETTING

Structure

Previous studies by Constenius (1981, 1982, and 1988), McMechan and Price (1980), McMechan (1981), and Price (1965) have shown that the origin of the Kishenehn Basin was related to displacement on the Flathead listric normal fault system, which borders the Kishenehn Basin to the northeast (Fig. 1). The Flathead system consists primarily of three fault segments: the Flathead fault, the Blacktail fault, and the Roosevelt fault. Displacement on the Flathead fault system increases symmetrically from the termini of the faults to an estimated 9 miles (15 km) or more along the medial part of the fault system. Similarly, the thickness of the Kishenehn Formation ranges from approximately 3,300 ft (1,000 m) near the end-points of the basin to an estimated 11,000 ft (3,350 m) in the center of the basin. Hence, an increase in displacement along the Flathead system is accompanied by proportional increases in basin width, displacement on antithetic faults such as the Nyack fault, the thickness of Kishenehn sediments, and the total amount of extension across the basin.

Furthermore, Constenius (1982, 1988) and McMechan (1981) have demonstrated that the structural position of the Kishenehn Basin with respect to the Lewis thrust fault is not coincidental, but reflects the common tie between these geologic features. The structural framework of the Kishenehn Basin was dependent on the configuration of the Lewis footwall ramp, which in turn controlled the amount of displacement on the Flathead fault system.

The South Fork Basin is also thought to be rooted structurally to the reactivated segment of the Lewis thrust fault. Because the basin has yet to be studied in detail, a tectonic understanding of the South Fork basin remains to be established.

Stratigraphy

Previous work by Constenius (1981), Constenius and Dyni (1983), McMechan (1981), McMechan and Price (1980), Jones (1969), and Price (1965) provided an understanding of Kishenehn sedimentation and stratigraphy, and documented the great diversity of lithologic types and associated facies in the Kishenehn Formation, in which deposits range from megabreccias and conglomerates to oil shales. Sedimentary structures, facies relationships, provenance, paleocurrent directions, and the characteristic "reverse drag" exhibited by Kishenehn strata indicate that displacement along the Flathead fault system controlled, and was in part coeval with, Kishenehn sedimentation. Orientation of imbricated clasts in alluvial fan sediments indicates that detritus originating in the uplifted footwall terrain of the Flathead fault system was transported to the southwest and deposited in the structural depression produced by the subsiding hanging wall block (Fig. 1).

The Kishenehn Formation has been lithostratigraphically divided into three informal members (Fig. 3): 1) basal member, found in the North Fork Region; 2) Coal Creek member, found in both the Middle Fork and North Fork regions; and 3) Pinchot Conglomerate member, which is best exposed in the Middle Fork region (Constenius, 1981). Probable equivalent units in the Canadian part of the Kishenehn Formation are the basal member, lower member and upper member, respectively (McMechan, 1981).

Strata of the basal member are found only in the North Fork region, and consist dominantly sandy conglomerates interbedded with subordinate pebbly sandstone, carbonaceous mudstones, and coals. Recognition of the basal member is based primarily on: limonitic staining which gives the strata a yellow-brown cast, sheared and pressure-marked conglomerate clasts, and stratigraphic position. Lithic clasts in the conglomerates are predominantly well rounded Proterozoic and Paleozoic quartzites. Thickness estimates for the basal member range from 460 ft (140 m) in Canada to an estimated 3,900 ft (1200 m) in the west central part of the basin. McMechan (1981) suggested that these sediments are sheetflood and channel deposits of a braided fan system.

Overlying the basal member are the Coal Creek and Pinchot Conglomerate members. These rocks are discontinuously exposed along the North Fork of the Flathead River and its tributaries. Rocks assigned to the Coal Creek member in the North Fork region are a heterogeneous assemblage of sandstones, siltstones, mudstones, lignites, oil shales, marlstones, and conglomerates. Although the Coal Creek member is lithologically very heterogeneous, its status as a member is based on its overall light grey color and fine-grained character. The estimated stratigraphic thickness of the Coal Creek member in the North Fork region is in excess of 11,500 ft (3,500 m). The Pinchot Conglomerate member is a 4,900 ft (1,500 m) (?) thick stratigraphic assemblage of red-brown colored, fine-grained and coarse clastic rocks. Interbeds of red-brown and grey, calcareous claystones/mudstones and grey, calcareous sandy conglomerates characterize this unit. The contact between these members is not exposed, but, is inferred to be conformable.

The Kishenehn Formation in the Middle Fork region (Figs. 1, 2, 3, and 4) is divided into the Coal Creek member and the overlying Pinchot Conglomerate member. The Coal Creek member, 3,770 ft (1,150 m) thick, is a heterogeneous assemblage of grey colored, well stratified, sandstones, siltstones, mudstones and claystones, lignites, oil shales, marlstones, and sandy pebble-cobble conglomerates. Coal Creek strata are subdivided into three sequences, each bounded by gradational contacts: a lower sequence, consisting primarily of lacustrine and deltaic sediments; a middle sequence, consisting dominantly of lacustrine sediments; and an upper sequence, characterized by intermixed sediments of alluvial fan, fan-delta, paludal, and lacustrine origin. The oil shales and sapropelic coals of the Coal Creek member have been the focus of three studies, Curiale (1987), Curiale *et al.* (1988), and Constenius and Dyni (1983), which concluded that they are excellent petroleum source rocks. The Pinchot Conglomerate member is a 660 ft to 2,300 ft (200 to 700 m) thick succession of alluvial fan sediments which conformably overlie the Coal Creek member, and are comprised of crudely stratified, red-brown colored, mudstones, sandstones, and conglomerates.

Kishenehn(?) strata in the South Fork basin (Fig. 1) consist of a variety of lithologic types, which range from vermilion colored mudstones to conglomerates. Thick beds of lignite and carbonaceous mudstones are also present (Erdmann, 1944), but oil shales and marlstones are rare. Mudge (1978) has reported that probable Miocene(?) conglomerates are present in the southern part of the basin.

TEPHRASTRATIGRAPHY

Kishenehn tephras are usually associated with the lacustrine facies of the formation. Consequently, the middle sequence of the Coal Creek member contains numerous tuff beds, in contrast to the other Kishenehn units, where tephras are relatively sparse. The thickness of these deposits ranges from thin laminations to beds as thick as eight inches (20 cm) for the Paint Creek Tuff. Initial surveys by our group found twenty-one tephras with a thickness in excess of one inch (2.5 cm) in the Kishenehn Formation. Fission-track and K/Ar dating results are presently available for two of these tephras (Figs. 1 and 4). These tephras are fine-grained and moderately bentonized, yielding a cream to light grey colored, clay-rich deposit in the field. Surprisingly, the Paint Creek Tuff of the South Fork Basin contains abundant platy and pumiceous clear glass shards, together with angular and euhedral glass-coated phenocrysts of predominantly quartz and feldspar. The morphology of

Figure 2. (Preceding page) Photo montage of Kishenehn Basin
geology and paleontology. ***Top Right.*** *View of Middle Fork* 1
region of Kishenehn Basin; looking west from Double
Mountain, across the forested basin floor of the Kishenehn
graben, toward Nyack Mountain in Flathead Range (see Fig. 4).
Kishenehn Formation appears as white colored cutbanks of
Middle Fork Flathead River. Roosevelt and Nyack normal faults
coincide with topographic breaks in slope at foot of Double
Mountain in foreground, and base of Flathead Range near
Highway 2, respectively. ***Upper Right.*** *Outcrop along Middle* 2
Fork Flathead River (see Fig. 4) showing: lower left, light-grey
colored strata of the Coal Creek member of the Oligocene
Kishenehn Formation; middle, maroon to red-brown colored
strata of the Pinchot Conglomerate member of the Kishenehn
Formation; and, upper right, tan colored, crudely stratified
gravels of the Quaternary(?) Paola gravel. Note conformable
contact of members and angular unconformity between
Kishenehn Formation and Paola gravel. Kishenehn strata dip 30
degrees NE. ***Lower Right.*** *Lower jaw of a new genus and* 3
species of dermopteran (Mammalia; "flying lemur"). ***Bottom*** 4
Right. *Crushed* Biomphalaria kishenehnensis *(Russel 1952) on*
bedding plane of thin sapropelic coal, Gastropod zone, middle
sequence Coal Creek member. ***Top Left.*** *Crane fly (*Diptera: 5
family Tipulidae*). This family lives in damp situations where*
there is abundant vegetation. The larvae are mostly aquatic.
Magnification 2X. ***Upper Left.*** *Deer fly (?) (*Diptera: *family* 6
Tabanidae*). This is a family of biting flies. The females are*
blood-sucking. Magnification 2X. ***Lower Left.*** *Locust* 7
*(*Orthoptera: *family* Acrididae*). A subtropical group which in*
recent times are known for their periodic outbreaks, in which
they devastate regional vegetation. Magnification 2X. ***Bottom*** 8
Left. *Large lobate leaf of* Macginitea angustiloba*. The previous*
known range of this leaf was Eocene, but, its presence in the
Kishenehn provides an important range extension into the
Oligocene and possibly indicates the existence of a vegetational
refugium in western Montana in the Oligocene.

these phases suggests the Paint Creek Tuff is a primary tephra-fall deposit derived from a distant source.

The provenance of the Kishenehn tephras is of interest because during the Oligocene, between 37 and 24 ma, volcanic activity in the northern Rocky Mountain region was relatively minor compared to the major volcanic fields that developed during this time in southern Utah, Nevada, southern Colorado, New Mexico and western Mexico (Lipman, 1984; Swanson and McDowell, 1984). However, Chadwick (1985) reports two small Oligocene volcanic fields in western Montana: (1) The Helena Field, 39 to 36 Ma, composed of scattered porphyritic quartz-sanidine lavas, aphanitic breccias, dikes and plugs, together with some ignimbrites and tephra-fall deposits; (2) The Hog Heaven Field, 31 to 29 Ma, comprised of andesites and latites. Although neither field is well-studied, it is unlikely that the Paint Creek Tuff was derived from the Helena Field, since this field is too old. In addition, the quartzo-feldspathic mineralogy of the Paint Creek Tuff is inconsistent with the leucite-bearing latites of the Hog Heaven Field. These observations suggest the source of the Paint Creek Tuff must be elsewhere, perhaps the San Juan Field, which is known to have erupted great volumes of dacitic to rhyolitic ignimbrites during the time of deposition of the Kishenehn Formation.

GEOCHRONOLOGY

The first fossils reported from the Kishenehn Formation were freshwater molluscs referred to Paleocene species (Daly, 1912). MacKenzie (1916), however, assigned the formation to the Eocene on the basis of additional freshwater mollusks collected from limestones. Russell (1952) considered the formation to be Middle Eocene in age on the basis of mollusks, but his later study (1954) of mammalian remains from the Kishenehn led him to reassign the deposits to the Late Eocene or Early Oligocene. Megafloral remains and molluscs from the North and Middle forks of the Flathead River indicated ages of late Eocene to early Oligocene (Ross, 1959). Palynological age estimates published by Hopkins and Sweet (1976) and McMechan (1981) suggest that the Kishenehn was late Eocene or early Oligocene and Oligocene, respectively. Written communications by Tschudy (1980) and Nichols (1981) stated that palynomorphs derived from the Kishenehn were probably from the late Eocene.

Daly's (1912) collections of Kishenehn mollusks were submitted to T. W. Stanton, who compared them to those of the Fort Union fauna. MacKenzie's (1916) specimens of aquatic mollusks were studied by W. H. Dall, who recognized the genera *Physa* and "*Planorbis*", and compared the planorbids to Eocene species of Wyoming and Utah. Russell's landmark papers (1952, 1956, and 1964) clearly described and illustrated the molluscan fauna of the North Fork region, and included many new species. Based primarily on associated mammals, Russell (1954) favored a latest Eocene age for the Kishenehn fauna, but he made no attempt to evaluate the environment of deposition. Ross' (1959) collections from the Paola Creek area of the Middle Fork region and the Kintla Creek area of the North Fork region were examined by both T. C. Yen and D. W. Taylor, who came to quite different conclusions as to age. Yen suggested a late Tertiary to Pleistocene age while Taylor, examining the same material, favored late Eocene to Oligocene, with one Miocene locality. Taylor (1975) reevaluated Ross' collection and reaffirmed a late Eocene age for most localities, with one Oligocene locality in the Kintla Creek area.

Our preliminary studies of the vertebrates, a fission track date of approximately 33.2 ± 1.5 Ma for the middle sequence of the Coal Creek member (C.W. Naeser, personal communication, 1982), and a K/Ar date of about 29.9 ± 5.3 Ma for the Paint Creek Tuff in the South Fork Basin (Teledyne Isotopes, 1985) indicate an Oligocene age for at least parts of the formation. The latter radiometric result is a K/Ar analysis of a whole-rock sample that is highly bentonized, and thus the reported age should be considered with caution. The age implications of the fossils are examined more thoroughly below.

PALEONTOLOGY

Paleobotany

Fossil leaves and other megafloral remains are common constituents of Kishenehn sediments, particularly in sandstone, oil shale, and coal deposits. The Kishenehn megaflora is moderately diverse but dominated by the platanoid *Macginitea augustiloba* (Lesquereux) Manchester, which indicates a humid, subtropical paleoclimate. Preliminary identifications show that other plants in the flora include *Cercidiphyllum, Metasequoia occidentalis, Fagaceae, Betula* or *Alnus, Castaneopsis* or *Castanea, Populus* sp., *Salix* sp., and *Malus* sp. Ranges of the known forms suggest a late Eocene date. This is not consistent with known radiometric dates and indicates that the Kishenehn Formation may preserve evidence of a vegetational refugium (Hickey, written communication, 1988).

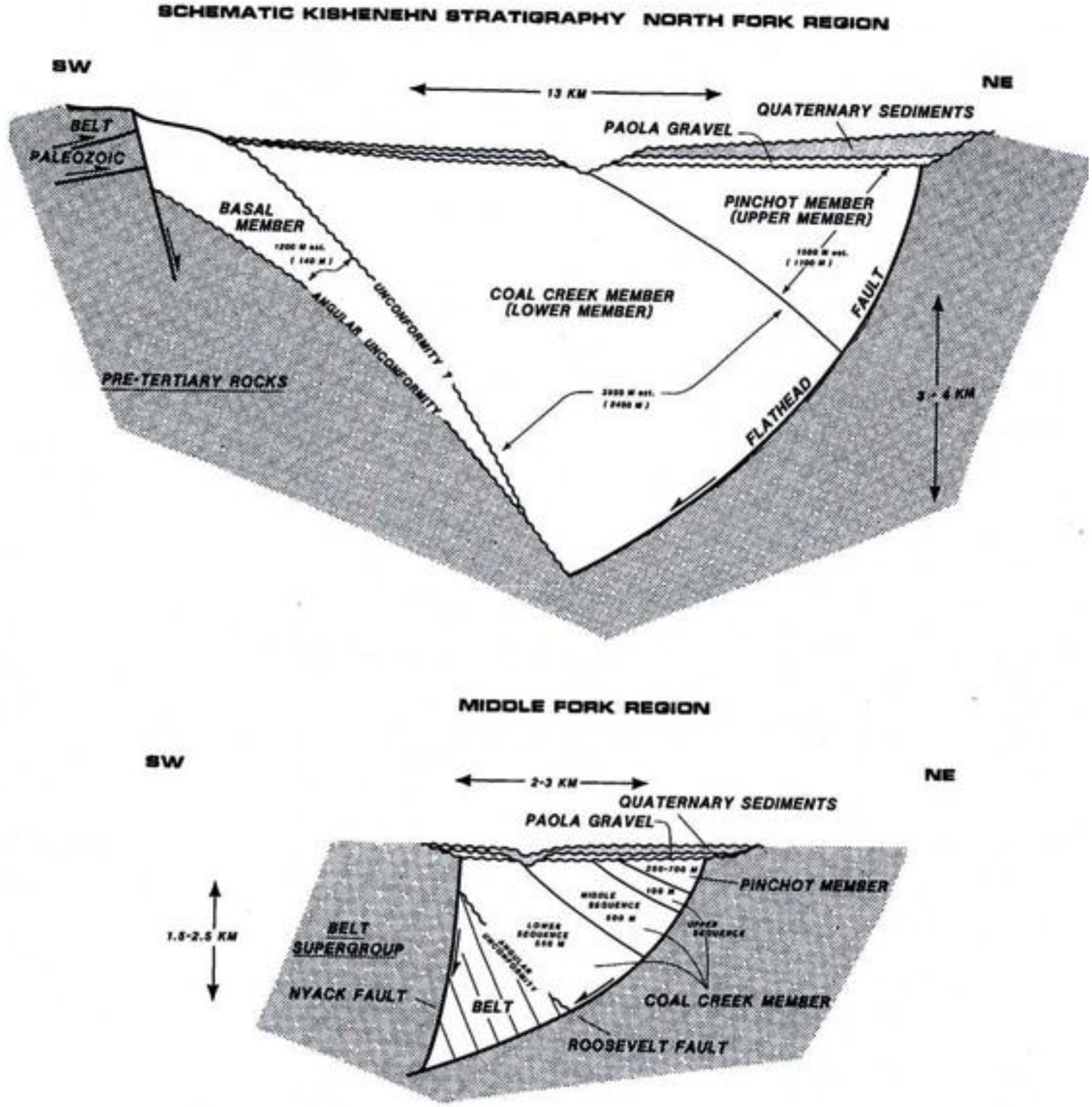


Figure 3. Schematic stratigraphy of the Kishenehn Formation in the Middle Fork and North Fork regions of the Kishenehn Basin. Nomenclature and thickness estimates for the Kishenehn in the North Fork region reflect both those of the authors for the central basin, and those of McMechan (1981) for the northern part of the basin which are shown in brackets.

Microfloral fossil sites are widespread in the Kishenehn Formation, in contrast to significant megafloral localities which are limited (Fig. 1). Kishenehn palynomorphs are commonly well preserved and characterized by a small variety of genera and species (Table 1). Studies in the North Fork region cited in McMechan (1981) indicated that conifers were the most common palynomorphs, with *Picea* (spruce) being is the most common genus. The prolific occurrence of conifers, the presence of Juglandaceae (*Carya*, *Pterocarya*, and *Juglans*) and the very rare occurrence of *Taxodium* (swamp cypress) suggest that relatively dry highlands bordered a basin dominated by lacustrine and paludal environments of deposition. The presence of *Typha* (cattails),

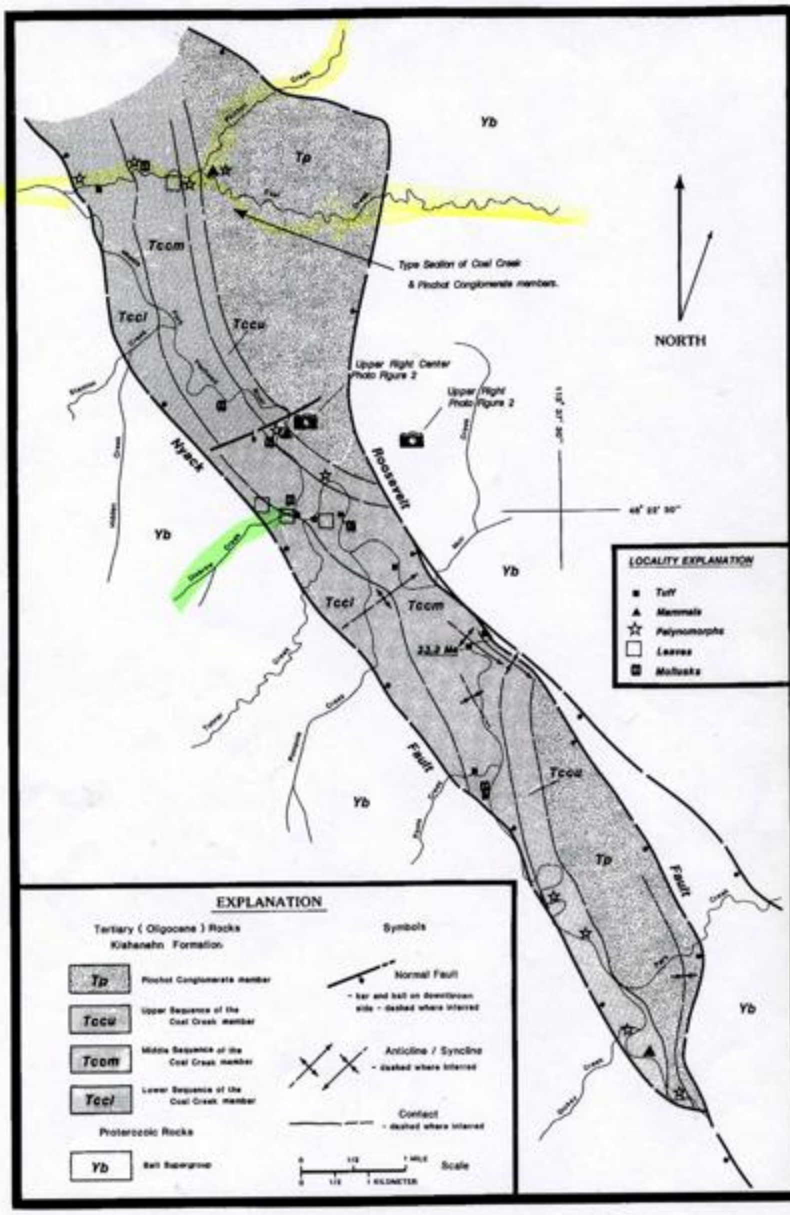


Figure 4. Pre-Quaternary geologic map of the Middle Fork region of the Kishenehn Basin. Significant fossil localities, tephra deposits and age dates are indicated.

Azolla (waterfern) and *Pediastrum* (algae) in parts of the formation are indicative of paludal depositional environments. Hopkins and Sweet (1976) as well as later studies of fossil pollen (Tschudy, 1980, Nichols, 1981, written communications) concurred with this assessment, identifying two environments: 1) proximal poorly drained lowland floodbasins in a humid, warm temperate to subtropical climate; and 2) distal highlands with a temperate to warm temperate climate.

Mollusks

Kishenehn gastropods are locally abundant, faunally diverse, and the most common of Kishenehn fossils. Planorbid gastropods are so prevalent in a part of the Coal Creek member in the Middle Fork region, that they serve to define a marker bed described as the "Gastropod zone" (Constenius, 1981). Except for the smaller

LYCOPODOPHYTA	
Family Lycopodiaceae	
Lycopodium sp.	
PTEROPHYTA	
Family Polypodiaceae	Family Azollaceae
Laevigatosporites sp.	*Azolla* sp. (megaspores only)
Family Osmundaceae	Family Salviniaceae
Osmunda sp.	*Salvinia* sp. (megaspores only)
GNETOPHYTA	
Family Ephedraceae	
Ephedra sp.	
CONIFEROPHYTA	
Family Taxodiaceae	Family Pinaceae
Glyptostrobus sp.	*Pinus* sp.
Taxodium sp.	*Picea* sp.
cf. *Metasequoia* sp.	*Tsuga* sp.
	Family Podocarpaceae
	cf. *Podocarpus* sp.
ANTHOPYTA	
Class Monacotyledonae	Family Aceraceae
Family Typhaceae	*Acer* sp.
Typha spp. (pollen and seeds)	Family Fagaceae
Family Liliaceae	*Castanea* sp.
	Fagus sp.
Class Dicotyledonae	*Quercus* sp.
Family Onagracea	Family Loranthaceae
?*Boisduvalia* sp.	Family Altingiaceae
Family Carpinaceae	*Liguidamber* sp.
Carpinus sp.	Family Salicaceae
Family Corylaceae	*Salix* sp.
Corylus sp.	Family Tiliaceae
Family Betulaceae	*Tilia* sp.
Alnus sp.	Family Ericaceae
Betula sp.	Family Ulmaceae
Family Nyssaceae	*Ulmus* sp.
Nyssa sp.	Family Nymphaeceae
Family Juglandaceae	cf. *Nuphar* sp.
Carya sp.	*Incertae sedis*
Engelhardtia sp.	*Tricolpites* sp.
Juglans sp.	*Triporopollenites* sp.
Pterocarya sp.	*Sigmopollis* sp.
CHLOROPHYTA (green algae)	
Pediastrum sp.	

Table 1. Preliminary list of the microflora fauna of the Kishenehn Formation (Hopkins and Sweet, 1976).

terrestrial taxa, specimens are usually badly crushed. Preliminary sampling of the Coal Creek member in the Middle Fork region and the Pinchot(?) member in the North Fork region has resulted in the identification of a number of new taxa, especially among the minute pupillids (Table 2). Some limited conclusions about environmental conditions during the deposition of the middle and upper sequences of the Coal Creek member are possible, even though molluscan specimens from the middle sequence are frequently crushed and fragmented.

Certain changes of previously used taxonomy may be justified. Taylor (in Ross, 1959) considered Russell's (1952) *Planorbis kishenehnensis*, the most common large planorbid, along with several other North American Tertiary species, to be conspecific with the European Eocene index fossil "*Planorbina*" *pseudoammonius* (Schlotheim 1820). This was based on the wide variation observed in single populations of the European species. Taylor (1962) later suggested that conspecificity with the modern Caribbean/South

	Russell		Ross	Taylor	This survey Coal Creek mbr.	
	1952	1956	1959	1975	middle	upper
TERRESTRIAL GASTROPODS						
Family Bulimulidae						
Oreoconus? n. sp.						X
Family Camaenidae						
Oreohelix sp.			X	X		X
Polygrella sp.			X	X		
Family Helminthoglypdidae or Camaenidae						
Genus and species indet.						X
Family Polygyridae						
Triodopsis buttsi Russell, 1956	X	X	X			
Family Urocoptidae						
Holospira adventica Russell, 1956		X				
Holospira n. sp., aff. *H. tamaulipensis*						X
Urocoptidae indet. (not *H. adventica*)		X	X			
Family Arionidae						
Binneya antiqua Russell, 1956	X					
Family Endodontidae						
Anguispira simplex Russell, 1956	X					X
Discus mackenziei Russell, 1956	X					X?
Family Zonitidae						
Hawaii, cf. *H. minuscula* Binney, 1840						X
Zonitoides?	X					
Zonitoides, cf., *Z. arboreus* Say, 1816						X
Ventridens?	X					
Family Pupillidae						
Pupillidae indet.		X	X			
Gastrocopta n. sp. A (*G. minuscula*)[1]						X
G. n. sp. B (*G. leonardi*)[1]						X
G. n. sp. C (*G. conica*)[1]						X
G. n. sp. D (*G. oviforma?*)[1]						X
Vertigo arenula White, 1876[1]						X
V. n. sp. A (*V. whitei*)[1]						X
Pupoides tephroides Roth, 1986						X
P. sp.						X
Family Valloniidae						
Vallonia sp.		X	X			
AQUATIC GASTROPODS						
Family Valvatidae						
Valvata procerus Russell, 1952	X		X			X
Family Hydrobiidae						
Hydrobiidae indet.		X	X			
Family Pleuroceridae						
Elimia sp.	X		X	X	X	X
Oxytrema?		X				

Table 2. Continued on following Page.

Continued From Previous page

	Russell 1952	Russell 1956	Ross 1959	Taylor 1975	This survey Coal Creek mbr. middle	This survey Coal Creek mbr. upper
AQUATIC GASTROPODS						
Family Lymnaeidae						
Lymnae newmarchi Russell, 1952	X		X	X		X
Lymnaea spp.			X	X	X	X
Family Physidae						
Physa sp.		X	X	X		X
Aplexa?						X
Family Planorbidae						
Biomphalaria kishenehnensis Russell, 1952	X	X	X[2]	X[2]	X	
N. Gen. A, aff. *Helisoma*			X	X		X
Omalodiscus n. sp., aff. *O. cirrus* White, 1879					X	X
Segmentina? n. sp., or n. gen. B.						X
Gyraulus n. sp., *aff. G. parvus* Say, 1817			X	X	X	X
BIVALVES						
Family Unionidae						
Elliptio salissiensis Russell, 1952	X		X	X	X	
Lampsilsis dalyi Russell, 1952	X					
Family Sphaeriidae						
Sphaerium progrediens Russel,l 1952	X					
Sphaerium sp.			X	X	X	X
Pisidium sp.			X	X	X	X

[1] These species will be described with names as indicated in a paper on the pupillids of the Cabbage Patch beds of southwest Montana by Pierce and D. L. Rasmussen, paper in review.

[2]Reported as *B. pseudoammonius* Schlotheim, 1820

Table 2. Preliminary list of the molluscan fauna of the Kishenehn Formation.

American "*P.*" *glabrata* (Say) was possible. Comparison of relatively uncrushed specimens of "*P.*" *kishenehnensis* from the middle sequence of the Coal Creek member with reference specimens of "*P.*" *glabrata* shows significant differences that warrant retaining "*P.*" *kishenehnensis* as a separate species. The Coal Creek specimens would represent a considerable geographic range extension for "*P.*" *pseudoammonius* that appears unwarranted. A ruling by the International Commission on Zoological Nomenclature (Opinion 735, 1965) has established precedence for the genus *Biomphalaria* for these species, therefore, *Biomphalaria kishenehnensis* is used here.

Mollusks were recovered from three distinct lithofacies in the middle sequence of the Coal Creek member, all in or near the "Gastropod zone" (Constenius, 1981): oil shale, calcareous siltstone-sandstone, and sapropelic coal. Gastropods recovered from the oil shale lithofacies consisted primarily of large, relatively uncrushed *B. kishenehnensis. Elliptio salissiensis* Russell (1952) was also recovered from this facies. The calcareous siltstone-sandstone lithofacies contained an apparently diverse but almost unidentifiably crushed fauna including smaller planorbids, *Elimia?*, *Lymnaea?*, immature *Elliptio?*, and abundant ostracodes. A diverse fauna of *Lymnaea, Physa, B. kishenehnensis, Omalodiscus* n.sp., smaller planorbids, and sphaeriid and immature unionid clams on bedding planes, were recovered from the sapropelic coals.

The middle sequence fauna is entirely aquatic, dominated by the large planorbids *B. kishenehnensis* and *Omalodiscus* n.sp. and beds of the bivalve *E. sasissiensis.* These three species provide conflicting environmental data. *Biomphalaria* is a subtropical to tropical genus, found as far north as the U.S. Gulf Coast, inhabiting larger, often shallow, weedy lakes. *Omalodiscus* is a Nearctic genus of Europe and Asia, with a report from North Africa, inhabiting generally shallow, standing to slowly flowing water. A single species, *O. pattersoni* (F. C. Baker 1938) is known from the North American Plio-Pleistocene. *Elliptio* is presently found in large, sandy bottomed rivers. This suggests a large, permanent, but not necessarily deep, lake with episodes of very low sediment input, due either to remote shoreline, baffling, or periodic lack of coarser clastic sediments. It appears probable that the lake was relatively warm, probably not unlike the present bayous of southern Louisiana and Texas.

Mollusks were recovered from three lithofacies in the upper sequence of the Coal Creek member: claystone; very fine to fine grained, poorly sorted sandstone; and marlstone. The faunas from these facies are very different from those of the middle sequence. The mollusks of the claystone facies, about 50 m below the top of the Coal Creek member, were so badly crushed during compaction that only the smallest species could be recovered in their entirety. Fragments recovered from the disaggregated samples were studied and, in many cases, were useful in establishing the larger taxa. From these a mixed terrestrial/aquatic fauna was identified. The aquatic portion was dominated by smaller planorbids, to include small *Omalodiscus* n.sp., a dentate and carinate planorbid tentatively placed in the Eurasian genus *Segmentina*, a probable new planorbid genus with affinity to *Helisoma* and a rather modern appearing *Gyralus* n.sp. Also found, but less numerous, were *Valvata procera* (Russell 1952), *Lymnaea newmarchi* Russell 1952, another large *Lymnaea*, a large *Physa*, *Aplexa* n.sp., and a possible *Elimia?* as well as sphaeriid clams and ostracodes. The terrestrial portion was quite diverse. The Pupillidae were represented by six species. *Vertigo arenula* White 1876 ranges from middle Eocene (upper Green River Fm., WY) to latest Oligocene - early Miocene Cabbage Patch beds of southwest Montana. *Pupoides tephroides* Roth 1986 is known from the latest Eocene - Oligocene Dunbar Creek Formation of southwest Montana. The four *Gastrocopta*, n.sp. A-D, are also known from the Cabbage Patch beds, and will be described as part of the Cabbage Patch molluscan fauna (Pierce and Rasmussen, in preparation). Additional taxa recovered, usually incomplete, include *Discus mackenziei* Russell 1956; *Anguispira simplex* Russell 1956; *Oreohelix?*; *Hawaiia* sp., cf. *H. minuscula* (Binney 1840); *Zonitoides* sp., cf. *Z. arboreous* (Say 1816); and *Holospira* sp., cf. *H. tamaulipensis* Barsch 1906. From a similar facies in the North Fork region, a badly crushed and fragmented helicoid snail of the family Camaenidae or Helminthoglyptidae, gen. and sp. indet., was recovered. The sandstone facies, about 20 m below the top of the Coal Creek member, yielded a small fauna similar to the claystone facies. It was composed of *Gastrocopta* n.sp. A, *Vertigo arenula*, *Holospira* n.sp., several small planorbids, and a large *Lymnaea*. Lastly, a single, relatively uncrushed *Oreoconus* was discovered in the marlstone facies.

The fauna recovered from the upper sequence provide more specific paleoenvironmental information than the fauna of the middle sequence. The aquatic fauna is notable in the absence of *Biomphalaria kishenehnensis*. The remaining genera suggest a large, probably shallow, lake with intermixed and surrounding marsh. All the genera can be considered Nearctic. Even *Elimia*, which has a present center of diversity in the southeast United States, has an isolated branch as far north as the Pacific Northwest. The large size of the lymnaeid and physid fragments suggest several seasons of growth in more or less permanent water. The general impression is of somewhat cooler water than that of the middle sequence, which may indicate a seasonal effect. The terrestrial species, except for three peculiarly western genera, *Oreohelix*, *Polygyrella*, and *Binneya*, could be assembled quite easily along the Gulf Coast of the United States. If Russell's (1956) *Ventridens?* sp. is, in fact, a *Sagda*, the fit would be even better. The western genera, with the exception of *Polygyrella*, whose presence was not confirmed, are genera tolerant of warmer climates. These fossil data suggest that the climate during deposition of the upper sequence of the Coal Creek member, was considerably warmer than the present, with precipitation adequate to maintain an essentially permanent lake and the moist-humid terrestrial lakeside environments required by most of the terrestrial genera. There is a evidence of seasonality that could be the essential difference between the middle and upper sequence sub-tropical to warm temperate climate change.

Insects

The first fossil insects from the Kishenehn Formation were discovered in 1982 by John and Leona Constenius, who initially found locust remains. The insect specimens from the Coal Creek member reveal a wealth of detail seen only in the best specimens from such Tertiary shale deposits as the Oligocene Florissant Formation of Colorado (Fig. 2). Preliminary study (Elias, written communication, 1988) suggests that the Kishenehn insects represent mostly a terrestrial, upland fauna of temperate zone affinities. A possible exception to this is a species of locust that may have more semitropical affinities. The fauna is diverse, with numerous families and orders represented, and contains herbivores, carnivores, scavengers, detritovores and parasites (Table 3).

Fishes

Initial studies of the fossil fishes of the Kishenehn Formation were carried out independently by Wilson, who followed up on discoveries by John and Leona Constenius, and by Dr. T. M. Cavender of Ohio State University. The combined preliminary collections include representatives of four families: Amiidae (bowfins), Hiodontidae (mooneyes), Clupeidae (herrings), and Catostomidae (suckers). Of these families, Amiidae are represented by one poorly preserved skeleton, and Hiodontidae and Clupeidae by rare articulated specimens. *Catostomidae* are by far the most abundant (Fig. 5). They are represented by a large series of articulated specimens from the lacustrine facies of the Coal Creek member in the Middle Fork region. Most of the specimens are small, with a standard length less than 3.1 inches (8 cm). However, several larger specimens have been found which attain a standard length of 13.8 inches (35 cm). Preliminary taxonomic study of this material suggests that more than one species of Catostomidae in the genus *Amyzon* is present; therefore, the number of species in the Kishenehn Formation is at least five.

ORDER ORTHOPTERA
- Family Acrididae (locust)

ORDER NEUROPTERA
- Family Raphidoidea (snake fly)

ORDER DIPTERA
- Family Culcidae (mosquito)
- Family Calliphoridae (blow fly)
- Family Syrphidae (bee fly)
- Family Tipulidae (crane fly)
- Family indet.

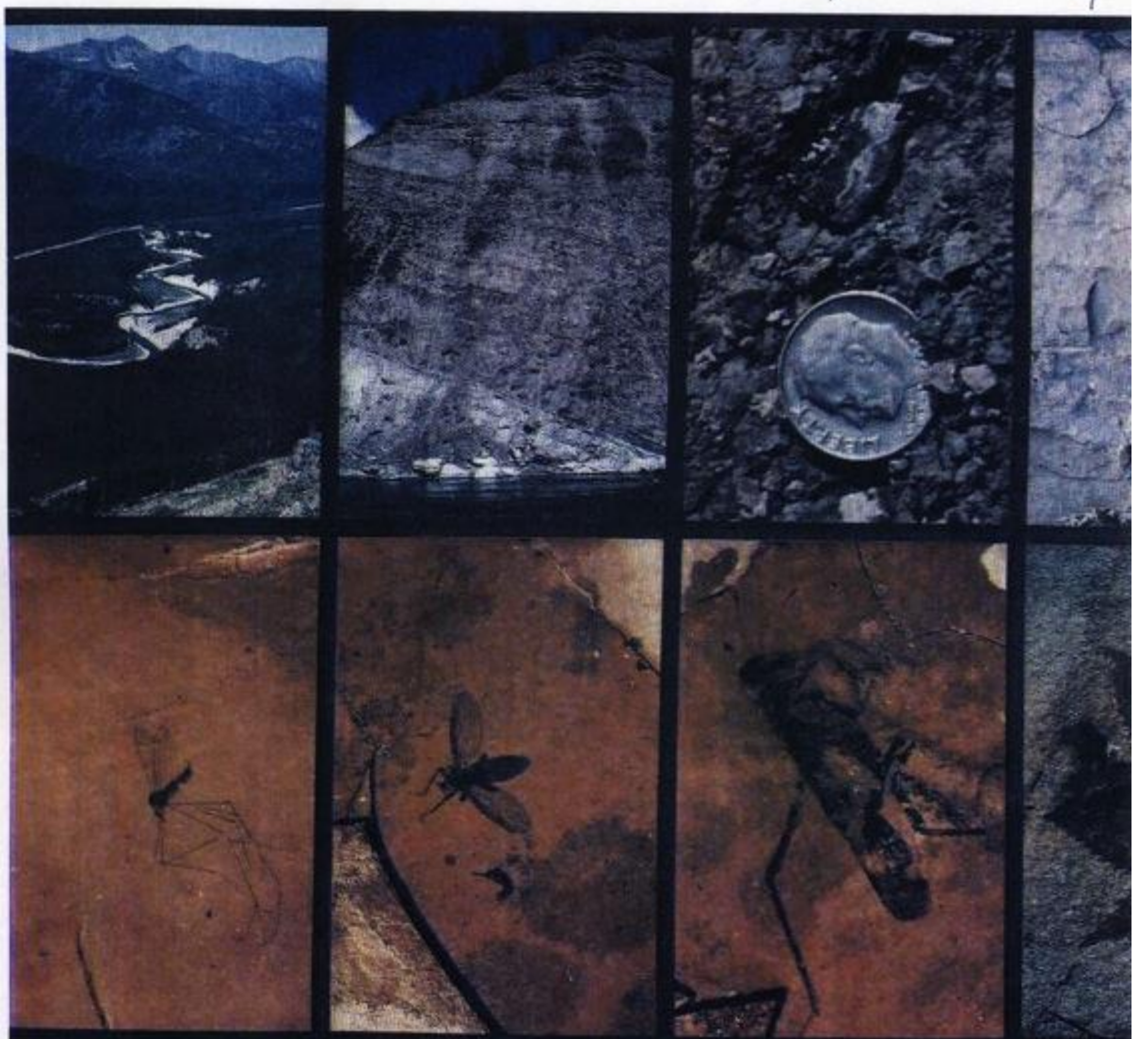
ORDER HEMIPTERA
- Family Pentatomidae (true bug)
- Family indet.

ORDER COLEOPTERA
- Family Scarabaeidae (dung beetle)
- Family Crysomelidae (leaf beetle)

ORDER HYMENOPTERA
- Family Braconidae (parasitic wasp)
- Family Vespidae (wasp)
- Family indet.

Table 3. Preliminary list of the insect fauna of the Kishenehn Formation

1 2 3 4



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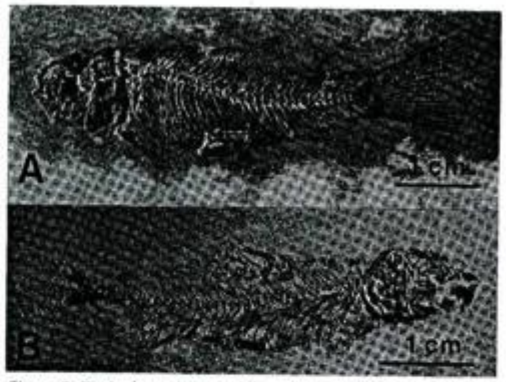

Figure 5. Typical specimens of the catostomid fish Amyzon *from the Kishenehn Formation. A. nearly undisturbed, complete specimen. B. complete specimen with fin rays, ribs, and jaw bones disturbed.*

Closely related taxa are known from other Eocene and Oligocene lacustrine formations in western North America, including the Eocene Green River Formation of Wyoming (Grande, 1984, 1985), the Eocene formations of British Columbia and Washington (Wilson 1977, 1982), the Eocene Clarno Formation of Oregon (Cavender, 1968; Elder, 1985), and the Oligocene of Florissant, Colorado (Cope, 1884). A number of other fish-bearing, Tertiary, lacustrine formations in Montana are important for comparison but are taxonomically less well known (eg. Cavender, 1977; Elder and Smith, 1988; Wilson, 1978, 1981). The extreme abundance of catostomids is similar to that occurring in several formations that are restricted in area and presumably were deposited in lakes of small to medium size. Alternatively, only the Green River Formation, which was deposited in several much larger lakes, is known to contain representatives of all four of the families found thus far in the Kishenehn Formation, although in the Green River Formation all four taxa do not normally occur in the same localities. Further collecting in the Kishenehn Formation will likely produce additional taxa that could clarify these comparisons.

Paleoecological information is contained in the distribution and state of preservation of fish in different layers. Relevant data include habits of related living species, as well as ages, sizes, and morphological features of the fossils themselves (Elder and Smith, 1988; Wilson, 1984, 1988a). One particularly important source of information is taphonomy, the study of conditions of death and burial based partly on the state of preservation of the fossils (Elder and Smith, 1988; Wilson, 1988b). The amount and kinds of decay and disarticulation of each fish can be compared with experimental data (Elder, 1985; Elder and Smith, 1988; Smith and Elder, 1985) and with similar data from other fish-bearing formations (Wilson, 1988a). Taphonomic analysis allows estimates of probable conditions on the lake floor, such as depth, turbulence, and oxygen content, together with possible causes and timing of death.

Specimens of fossil fish collected thus far consist primarily of completely articulated to only slightly disturbed skeletons (Fig. 5A), including some examples of mass-death layers. The kinds of disturbance recognized so far include possible examples of vertebral disturbance by decay gases and slight displacement of fin-ray segments by gentle currents (Fig. 5B). These observations are consistent with preservation in the deeper parts of a stratified lake.

The fossil fishes of the Kishenehn Formation have the potential to contribute significantly to studies of fish systematics and evolutionary paleobiology. The existence of large series of catostomid specimens from numerous stratigraphic horizons may provide an opportunity to study intraspecific variation in one or more fossil species over time. Finally, taphonomic and environmental data from the fishes will aid in the reconstruction of Kishenehn paleoecology.

Mammals

The first fossil mammals from the Kishenehn Formation were found in 1952 by Russell and colleagues working along the North Fork in British Columbia. The fauna was considered to be Duchesnean or Chadronian (Russell, 1954). The only other mammal from the British Columbia section was reported by McMechan (1981), who found a partial skull and jaws of an oreodont along Commerce Creek in 1977. He considered the specimen to represent *Merycoidodon* sp. *cf. M. culbertsoni* and to indicate an Orellan age.

Dawson began vertebrate paleontological work in the Kishenehn Formation in 1967, working first at the previously reported localities of Russell in British Columbia and later discovering new mammal bearing localities within Glacier National Park near Kintla Creek. Outcrops of the formation that were examined were scattered and restricted to cut banks along the North Fork and its tributaries. In 1980 Dawson began work with Constenius in the Middle Fork region. This collaboration was continued in 1981, 1985, and 1986, and many promising mammal sites were found. Preliminary field reconnaissance in the South Fork Basin has revealed deposits that appear to be appropriate for screen washing, but no vertebrates have been discovered there so far.

The known Kishenehn mammalian fauna (Table 4) is generally Oligocene, but it has a number of unique features. For example, the peculiar *Thylacaelurus*, described as a marsupial (Russell, 1954), but later referred to a new subfamily of Dermoptera (Van Valen, 1967), is known only from the Kishenehn Formation. Another dermopteran, discovered during the 1986 field season (currently under study by McKenna), is known elsewhere only from related Eocene species (Fig. 2). The occurrence of dermopterans ("flying lemurs") in the Kishenehn is significant, because it may corroborate paleobotanical evidence that subtropical forests bordered the basin. Flying lemurs are present today in the tropical forests of southeast Asia. Squirrels are prevalent in the Kishenehn, in contrast to other Oligocene localities in the western U.S. where they are rare. Lagomorphs are rare, which is unusual for Oligocene strata. The eomyids and cylindrodontids are quite similar to Oligocene species from the Great Plains and intermontane basins of southwest Montana. The cricetid rodent, however, is not a eumyine, which is the common cricetid group in the plains. The diversity of aplodontids is also not characteristic of most known Oligocene faunas. Bats, shrews, hedgehogs, and moles are represented. Of larger mammals, only artiodactyls have been found. The faunal province represented by this assemblage, or series of assemblages, is like no other assemblage in North America.

CONCLUSIONS

Preliminary work on the pollen, leaves, insects, fishes, and mammals of the Kishenehn Formation is bringing together lines of information on the late Paleogene biota of northwestern Montana. Inconsistent age estimates are provided by the known fossils, ranging from late Eocene to early Miocene. This suggests, in part, some time span for Kishenehn deposition, but also seems to reflect a mixing of floral and faunal types, and thus an environment, unknown elsewhere. Further study of stratigraphically placed

HO MYO — 20 MYO !

ORDER MARSUPIALIA	
Family Didelphidae[1]	
Peratherium spp.	
ORDER INSECTIVORA	
Family Soricidae	Family Erinaceidae
Domnina sp. 1	cf. *Ocajila* spp.
Domnina sp. 2	Family Talpidae
Family Apternodontidae	talpid sp.
Oligoryctes sp.	
ORDER CHIROPTERA	
ORDER DERMOPTERA	
Family Thylacaeluridae[1]	Family Plagiomenidae
Thylacaelurus montanus	n. gen. and sp.
ORDER LAGOMORPHA	
Family Leporidae[1]	
Desmatolagus sp.	
?Mytonolagus sp.	
ORDER RODENTIA	
Family Aplodontidae	Family Cylindrodontidae
2 or 3 spp.	*Pseudocylindrodon sylvaticus*
Family Sciuridae	cylindrodontid sp.[1]
sciurid sp. 1	Family Eomyidae
sciurid sp. 2	*Adjidaumo burkei*
Family Cricetidae	*Adjidaumo* sp.
n. gen. and sp.	*Paradjidaumo alberti*[1]
n. gen. and sp.	*Paradjidaumo* sp.[1]
ORDER ARTIODACTYLA	
Family Leptomerycidae	Family Merycoidodontidae
Leptomeryx sp.[1]	*Merycoidodon* sp.[2]
cf. *L. evansi*	c.f. *M. culbertsoni*

[1]Russell, 1953; [2]McMechan, 1981; Dawson, unpublished.

Table 4. Preliminary list of the mammalian fauna of the Kishenehn Formation.

assemblages and associated radiometric dates will determine how much of the uniqueness of the Kishenehn assemblages is related to time span and how much to a real floral and faunal mixture of temporal indicators.

The floral and faunal transitions within the Kishenehn Formation may reflect climatic cooling that occurred around the Eocene - Oligocene transition. For example, the abundant and diverse mollusks, which are suitable for determining details of environments, document a change from more tropical to seasonal warm temperate climatic conditions between middle to upper parts of the formation.

Reconstruction of the lacustrine paleoenvironment will be facilitated by studying the fossil fish. Of special interest will be determination of habits of living relatives, age structure of the death assemblage, and taphonomic inferences about causes of death and post-mortem conditions in the lake. There is the potential for these data to be specific with respect to stratigraphic layers, leading to possible conclusions about temporal variation in paleoenvironments. Some of the fish taxa are probably distinct at the species level from species in other assemblages of comparable age, but the genera are fairly typical. Therefore, the assemblage is not greatly different from those of similar age elsewhere. More than anything else, it is the excellent preservation that makes these fish especially valuable for phylogenetic and taxonomic studies.

The central theme of the Kishenehn Basin Study project is to attain, through the efforts of a multidiscipline study team, a comprehensive understanding of Kishenehn paleoecology, paleoenvironments, and geochronology. Systematic subsidence of the basin has preserved a relatively continuous record of deposition, however, a detailed reconstruction of the history of the Kishenehn is limited by the exposures, facies and fossil record of these rocks. Summarized in figure 6 is the stratigraphic placement of the various fossil types and tephras utilized in this reconnaissance study. Further field investigation and continued interaction of the various

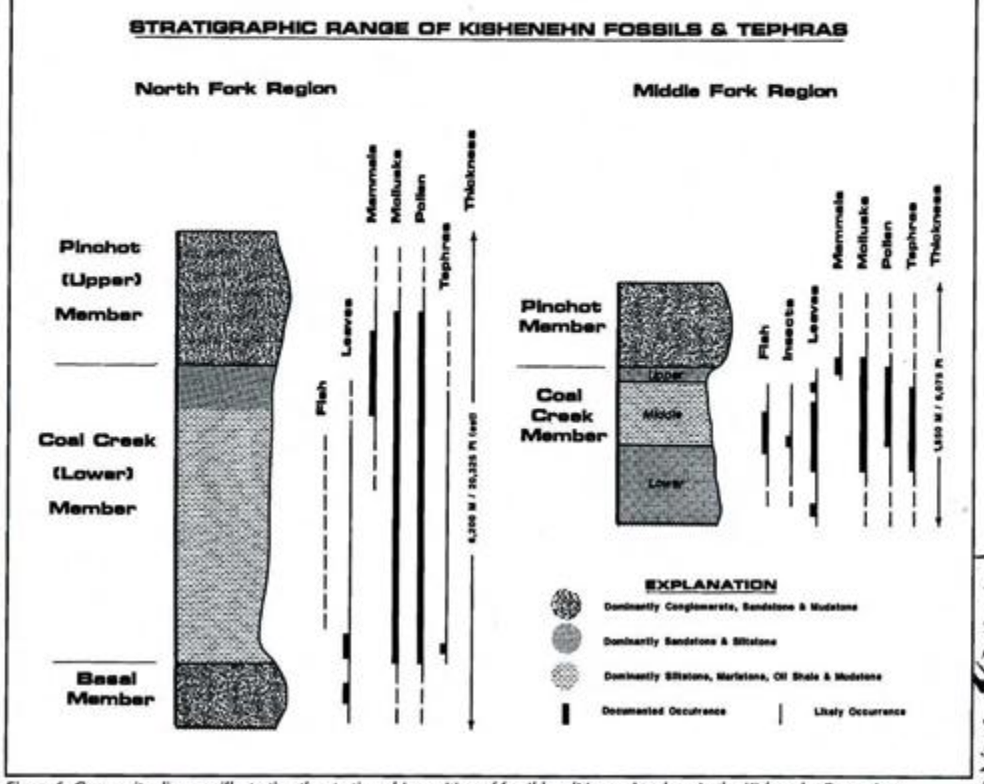

Figure 6. Composite diagram illustrating the stratigraphic position of fossil localities and tephras in the Kishenehn Formation.

disciplines in assaying this network of data should result in a thorough understanding of the origin and nature of the Kishenehn Formation.

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